THE NEWTONVILLE SAND-PLAIN.

1. *Introduction.*—During the past year the writer has studied the Newtonville (Massachusetts) sand-plain under Professor Davis, of Harvard University, and after studying the deposit as it now exists, made a detailed map of the plain with its feeding esker. Then a model of the region was made in clay on the scale of 1:4000. This clay model was photographed, and is here reproduced in half-tone, in Fig. 1, Newtonville Sand-plain. The conditions of formation were then studied, and a second model constructed, showing a conjectural relation of deposits to the margin of the New England ice-sheet at the time of its formation. A photographic reproduction of this is given in Fig. 2, Ice-sheet Restored.[1]

2. *Making the models.*—The clay was built up in a solid mass to the greatest required height, and the details of form were then cut with graving tools. In making such models it is essential that the foundation for the clay should be firm and not liable to warp. A slate slab, or a piece of heavy plate glass answers the purpose well. While at work on the model it is important to keep the clay moist. So a box lined with rubber cloth should be provided, large enough to cover the clay without touching it, and an inner layer of muslin put in to hold the water. When the model is ready to have a plaster mold made, the edges should be trimmed square, tapering slightly up from the slate so that the mold will slip off easily, the surface oiled, boards placed an inch and a half from the four sides, and liquid plaster poured over it. After the plaster has set, it may be wedged up from the slate or glass, and lifted from the clay. Then the plaster negative should be carefully washed with a brush to remove all oil or clay stick-

[1] Teachers or others who desire copies of models, photographs, or lantern slides can arrange for them by corresponding with the writer.

ing to it, and when hardened with a thin solution of glue and dried it is ready for the taking of a paper positive. This *papier-maché* model is a close representation of the original clay.

3. *A late glacial deposit.*—A glance at the first model will show the typical form of these delta deposits, the esker like an arm, and the sand-plain like a hand with its finger lobes. The esker rises in height as it approaches the head of the plain. The top of the sand-plain slopes very gently downward from the head to the top of the lobes, but the front slopes of the lobes are much steeper, about twenty degrees.

The sand and gravel are so little disturbed that the deposit cannot be pre-glacial. That the deposit was not made by marine or fluviatile action is shown by the three following considerations. First, an aqueous deposit of gravel, composed of fragments from the crystalline high-lands between two and three miles to the north, should have extended originally from its source outward; but the amount of denudation and transportation required to cut out these delta deposits from a continuous sheet extending across the Charles river to the crystalline highlands on the north, whence a large part of the fragments come, would be greater than the post-glacial denudation that has been measured elsewhere. Second, the delta front and the even sloping delta-plain imply standing water, and if this water level existed for so long a time as would be required to form such an extensive deposit, we should expect to find more evidence of its shore line in other localities than now exists. Third, the constructional forms, cusps, hollows, kettle-holes, at the head of the sand-plain are so marked that one cannot believe them to be the product of erosion. The kettle-holes and marshy depressions show that the plateau tops did not extend much farther than at present.

The dwindling New England ice-sheet, whose existence is proved by other facts, supplies all the conditions necessary for the construction of such discontinuous deposits. The ice-sheet could not have advanced over the plain after its deposition, for the sand and gravel would have been easily carried away. There is no gullying of the sides of the sand-plain; therefore it was

FIG. 1.

formed not so very long ago. .But the gravel is evidently of glacial origin, being of angular and subangular pebbles, of great variety of material. The conclusion seems inevitable, therefore, that these deltas were formed during the retreat of the ice-sheet.

4. *Stagnant, melting ice.*—In the retreat of the ice-sheet there were parts at least which became too thin to move. As Professor Davis has said:

> During this time it must have melted irregularly, presenting a very uneven, ragged front, from which residual blocks may have been frequently isolated; and it must have endured longest in the valleys, where it was thickest, not only by reason of its greater depth, but also because its surface there, where motion had been fastest and longest maintained, must have been higher than on the hills—this being homologous with the variation in the thickness of a Swiss valley glacier from middle to sides."[1]

It seems to me that we must consider the change to have been gradual from a moving glacier to a stagnant one, and that there may have been times of renewed activity with a forward motion, even in the period of decline. Such forward motion may have had some influence in shifting the course of esker rivers and so have determined where the next sand-plain was to be built. So far as I know, this point has not been worked out in the field.

Crevasses are formed as the ice moves, and change their position according to the tensions in the mass of the glacier. When the tension from motion has ceased, and the ice has become a diminishing, drift-covered mass, the condition represented in Fig. 2, we should not expect to find any crevasses remaining. They would either have been closed by the forward motion of the ice, or would have lost their distinctive character by the excessive melting of their sides, while the water would have washed detritus into them covering the underlying ice, and preventing it from melting as fast as that on either side. Such protection of the ice by detritus must have had great influence in determining the surface forms of the stagnant ice-sheet, as is shown in Professor Russell's account of the sand cones and the deposits in glacial lakelets.

[1] Bull. Geol. Soc. of Am., Vol. I., p. 196.

5. *Comparison of models.*—Turning from Fig. 1, which shows the deposits as they exist to-day, to Fig. 2, which shows the theoretical conditions of formation, it will be seen that the northern half is covered with ice, from which is issuing an esker river. The ice in the second is represented as fitting into the intercuspate hollows shown at the head of the sand-plain in the first model, and is from one hundred to three hundred and fifty feet thick. Toward the rock hills on the east and west it falls off, as would be the case where the ground was higher. The ice has a convex curving surface in front, with contours softened by melting, while on top it is approximately level with here and there surface streams, moulins, and perhaps a little lake.

The three little knobs of older date than the sand-plain standing near its front margin, can be seen in both models. The till-covered hills of bed rock are also the same in the two, but in the second the water stands higher up on their sides. The second model being a trifle larger, a little more of them is shown on the edges. The group of hummocky kames, shown to the southwest of the sand-plain in the first model, is covered in the second by the body of standing water into which the esker river flowed.

6. *Esker river.*—Professor Chamberlin has given us the very helpful distinction between "kame" and "esker" (osar), from the use of the words in Scotland and Ireland respectively. The former is used by the Scotch for their irregular mounds and hillocks, so typically shown in that country, and which, if developed at all in lines, have their axes at right angles to the direction of ice flow; and the latter for the Irish ridges of sand and gravel, beds of former glacial rivers, which have their axes parallel to the lines of motion in the ice. This terminology is here followed.

In the first model the esker, a ridge of sand and gravel, fairly stratified, may be traced from the middle of the northern end, where it is some ten to twenty feet high, curving eastward and then southward again, gently rising to some seventy feet above the alluvial plain shown on the northwest corner of the model of the sand-plain, and one hundred and thirty feet above mean tide.

Then it falls ten feet, and, curving a little to the west, rises thirty feet to where it reaches its greatest elevation, one hundred and fifty feet above mean tide. This is also the elevation of the front of the sand-plain. At this point it breaks up into several more or less clearly defined branches, which distribute the sand to build up the delta in the estuary.

These branches fall off in height towards the head of the sand-plain, as is often seen in similar deposits elsewhere. As it has been shown that the amount of post-glacial erosion has been small, this depression must be due to conditions existing while the ice was present. The first model shows a large kettle now occupied by a pond which lies north of the sand-plain and east of the esker. This depression, being filled with ice after the course of the esker river was changed, must have had an outlet, and as the main body of ice would have prevented the formation of an outlet on the north, it seems reasonable to suppose that this water quietly cut through a slight sag in the esker to the west. This cutting would have continued until the ice-sheet had retreated farther north, and the ice block in the kettle had melted, and its depth would be governed by the amount of the lowering of the water in the estuary, caused by rising of the land.

Two branches from near the north end of the esker run into cusps at the head of a second smaller sand-plain deposit, formed when the ice-front had retreated some two thousand feet, and while the ice remained at this second point there would have been no outlet for the water to the north. The frontal lobes of this second sand-plain are not at all typically developed.

7. *Delta streams.*—In front of the openings of the esker tunnels will be seen the depositing streams breaking up into many branches, as Professor Russell has described them in Alaska[1]. Some of them are represented as having already ceased to flow to the edge of the delta, and are fast filling up; others are pushing out their resulting lobes as far as they can reach; while a third class are supplying detritus to those in front, and are building up their channels to give themselves greater carry-

[1] See Malaspina Glacier, page 238.

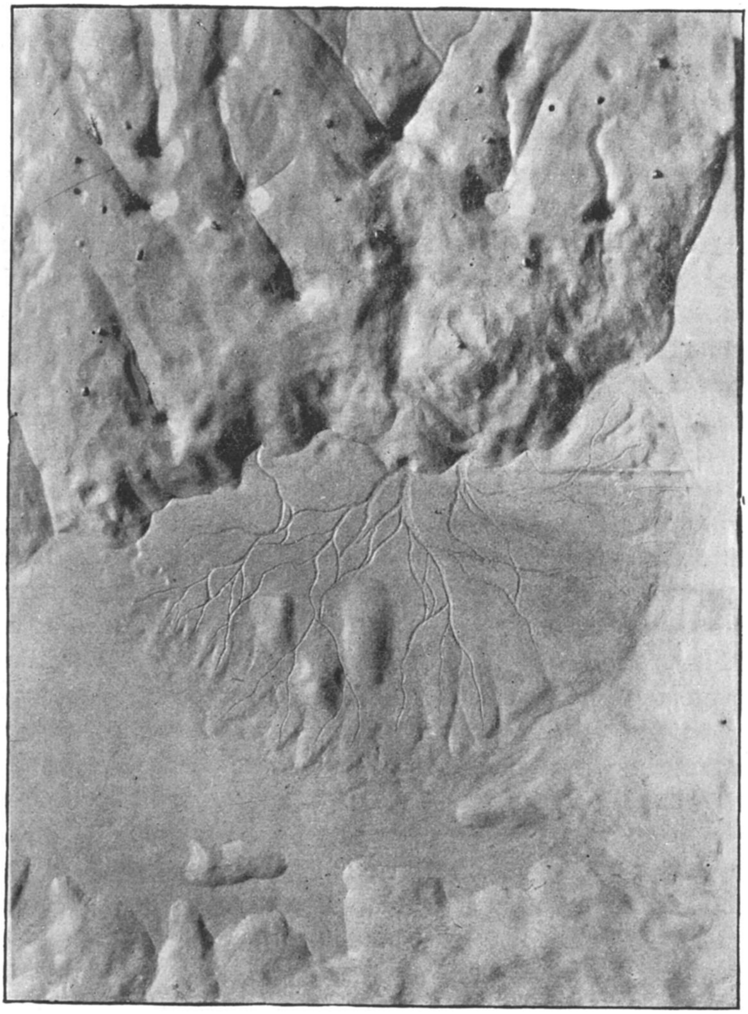

FIG. 2.

ing power by increasing their slopes. The front lobes are too strongly shown in the photograph, Fig. 2, as they were left to show the limits of the delta. In the *papier-maché* copies, the water completely covers the slopes of the lobes.

On this deposit, which is 4000 feet from east to west, and 2000 to 3000 feet from north to south, there is only one small kettle-hole. This lack of kettle-holes, so abundant elsewhere, may be taken as an indication that the ice-sheet was comparatively continuous at this time. It evidently became more broken immediately after the course of the esker stream was changed, as there are several kettle-holes to the north of the sand-plain.

8. *Superglacial streams.*—These are represented on the model as smaller than the main channels below, and more inconstant in direction. Their development after the closing up of the crevasses has been made the subject of special study, and its results are shown on the model. Other conceptions of this surface will no doubt occur to many, and any criticism or suggestion will be gladly received. One of the processes that has been a prominent factor in the determination of the form of the surface is that described above, where the detritus in the bed of the stream protects the underlying ice. Little accidents of melting and washing would shift the course of these streams, so that the arrangement of them upon the surface would not be shown by any deposits to-day. As soon as one of these streams found an opening through the ice, a moulin would be formed.

9. *Moulins and kames.*—In the second model I have made moulins in the ice-sheet above the kames in the first model, though I should not like to be understood as affirming that all these kames were surely formed in this way. It is quite probable that further study would show facts pointing to several geneses. Professor Chamberlin says, in speaking of the formation of similar deposits :

"No existing agency, by any extension of its magnitude, is at all competent to account for their localization. The formative agency, or combination of agencies, must have produced, at once, local assortment and local heaping of the assorted material, or, in other words, the assorting waters must have

been confined and concentrated in their derivative action, and likewise constrained so as to heap their material into tumuli, whose location was determined by the constraining agency more than by any feature of the local topography or other present condition."[1]

That some kames are moulin-kames seems to be undoubted, and perhaps we may best picture to our minds their formation by turning an hour-glass and watch the sand heap itself up. A certain amount of stratification will take place in air, which would be increased when the air is replaced by water.

10. *Shore-line.*—With the working hypothesis that this sand-plain was formed in a body of standing water, I reached the conclusion that it was at the head of an estuary. With the existing topography to the south it is almost impossible to conceive of the water as having been enclosed. Such a pond would require too many dams not now existing. If one accepts the delta front as proof of a body of standing water, he seems forced to conclude, on looking over the ground, that the Newtonville sand-plain was built in an arm of the sea. If so, the estuary must have connected with the Atlantic along the present course of the Charles river and through Mother brook to the Neponset. It must have had a very temporary shore-line at any given level, as there is hardly a trace of it now on the till-covered slopes, except in one place on the east bank of the Charles river, about a mile southeast of Newton Upper Falls where Dr. T. W. Harris found a faint cliff, as if made by shore cutting, with a long, gently shelving slope below it. In representing this shore-line on the second model, I have tried to show no beach effect, but to indicate that the land was but recently submerged, and that the water conformed to the contour of the till-covered slopes.

11. *Relation to other sand-plains.*—The intimate connection between the Newtonville sand-plain and the one immediately to the north of it, branches of the same esker running to each, suggests a connection of this bit of the history of our New England ice-sheet with other portions. Were the Auburndale sand-plains formed before or after the Newtonville ? What other esker

[1] Am. Jour. of Sci., 1884, p. 381.

rivers emptied into this estuary? When should we expect to find terraces on either side of a sand-plain, as at Pawtucket, R. I.? Why are not sand-plains of more frequent occurrence throughout the area covered by the ice-sheet? These and many other questions are suggested as we study the details of the ice's work. Their answers await the future study and research of those local observers, who will make themselves familiar with the geographic forms of their own regions.

F. P. GULLIVER.

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